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RECLAMATION OF URBAN AREAS

Jørn Roed

Abstract. A literature study was conducted in order to compare the effectiveness and cost of different reclamation procedures that may be employed after an accident on a nuclear facility takes place in which radioactive material is released to the atmosphere.

A substantial amount of work has been done on reclaming soil and snow-covered surfaces. Using scrapers or other soil-moving equipment decontamination factors are 10-100. (The decontamination factor is the ratio of the contamination before to that after the decontamination procedure). However, information on decontamination of paved areas by simple methods such as fire-hosing and vacuum sweeping are poorly documented. Therefore, only a very uncertain figure in the range 2-10 can be given for the decontamination factor here. It is recommended that a major

(continued on next page)

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effort be made in the future to investigate the efficiency of these simple methods, because of their relatively low cost. Also, more expensive methods for reducing the dose such as vacuuming, road planing and deep plowing are treated because of their feasibility under certain circumstances. Using these methods dose reduction factors in the 2-100 range can be obtained. Very expensive techniques, such as sandblasting, water cannon, flame spalling, etc. are justifiable usable only in special situations and are therefore considered very briefly here.

The methods vary widely in cost. A simple method like vacuum sweeping costs $0.004 per square meter of surface; whereas one like road planing can reach $4 per square meter. A more sophisticated technique like flame spalling costs as much as $100 per square meter.

INIS descriptors: COMPARATIVE EVALUATIONS; COST; DECONTAMINATION; LAND RECLAMATION; RADIATION DOSES; REMEDIAL ACTION; REVIEWS; SNOW; SOILS; SURFACE CLEANING; URBAN AREAS

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1. INTRODUCTION AND DEFINITIONS

To counter the effect of nuclear accidents that have released radioactive materials to the atmosphere with appropriate procedures, it is important to evaluate them in terms of their cost and effect.

This study, however, will treat only reclamation, i.e. the part of the countermeasure procedure that deals with the reduction of radiation exposure by removing deposited material or burying it in place, e.g. by firehosing or plowing.

Decontamination is the category of reclamation that is limited to removing deposited material from a target component, e.g. by firehosing a roof or sweeping a paved surface. Warming (1984b) has also treated this subject.

The effort of the reclamation procedures is, of course, strongly influenced by the amount of the material deposited, as characterized by the surface, and by the potential detriment of the contamination.

Wet deposition in the form of rainfall during the passage of a plume may cause a very uneven distribution on the artificial materials comprising a large fraction of the surfaces in an urban region. This is because urban surfaces are highly impervious to prevent infiltration and thereby cause run-off that is normally carried away through gutters. Vertical surfaces could be left nearly uncontaminated, whereas pervious surfaces such as lawns, parks, gardens etc. could be heavily contaminated.

Wet deposition in the form of snow could, however, produce a high contamination level on impervious surfaces as well.

Dry deposition strongly depends on the character of the surface over which the plume passes.

Unfortunately, most measurements of the deposition velocity are made over vegetated areas, particularly over grass. Only a few deal with urban surfaces (Roed 1983 and 1985). However, there are reasons to believe (Roed 1981) that the deposition velocity and thereby the amount of deposited material is much higher on rough surfaces such as parks and lawns than on smoother surfaces as parking lots.

The interest in reclamation of radioactive contaminated urban areas is not restricted to a study of the consequences of reactor accidents. Information is also needed to plan recovery operations on areas exposed to fall-out from nuclear attacks.

Unfortunately, the substantial amount of information available on reclaming of areas contaminated with fall-out from nuclear weapons cannot always be used to give reliable information on the results of a similar reclamation procedure in connection to power accidents. This is due to the different distribution of particle sizes from the two different sources (Linsley 1984). Fall-out particles from nuclear explosions are normally large (>10 μm) in the vicinity of the detonation site, whereas those released from a nuclear reactor are expected to be much smaller. Bunz (1980) found that the mean size of the particles in the reactor containment after an accident were less than 3.5 μm in all cases, so that the mean size of particles released to the atmosphere will also be less than 3.5 μm.

The decontamination efficiency on impervious surfaces can be strongly influenced by the particle size, whereas this size has little effects on with the efficiency of reclamation procedures carried out on lawns, parks, and gardens or under winter conditions.

The next chapter deals with those comparatively simple and inexpensive reclamation procedures in which necessary material and manpower will be normally available. Such procedures are, e.g., sweeping, vacuum-sweeping, firehosing, scraping, plowing, overturning flagstones, vacuum cleaning, digging, and snow removal.

The following chapter deals with more sophisticated techniques such as sand-blasting, flame spalling, water cannons, etc.

2. SIMPLE METHODS

2.1. Sweeping and vacuum-sweeping

2.1.1. Paved surfaces

Sweeping or vacuum sweeping is a common practice in essentially every street in an urban area, but even under well-operated and highly efficient street sweeping programmes the efficiency of small-particle removal is often low.

Sartor et al. (1974) found that the sweeper efficiency was 15% for particles less than 43 μm and the overall efficiency for all particle sizes was 50%, considering a normal effort to be 2.56 min/1000 m^2. The overall efficiency of 50% could be raised to 70% by increasing the effort 2.1 times and to 95% by increasing it 6.3 times. They found a mathematical relationship for calculating the effectiveness of removing the dust and dirt fraction within each particle size range.

$$M = M^o + (M_o - M^o)e^{-kE}$$

where M is the amount of street surface contaminant remaining after sweeping, M_o the initial amount of contaminants, E the amount of sweeping effort involved in using the equipment, min/1000 m^2 and M^o and k are dimensionless constants dependent on sweeper characteristics, particle size of contaminant and street surface.

The findings of Sartor et al. agree well with Clark and Cobbins (1963). Their results as reproduced in WASH 1400 (NRC 1975) indicate that the efficiency of the methods is sensitive to the particle size and initial mass loading, in such a way that the method would be inefficient for particles smaller than 20 μm and initial mass loadings below 1.0 g/feet^2.

The present literature study revealed only one paper (Calvert 1984) dealing with the efficiency of removing particles less than 5 μm by sweeping. The efficiency was determined by measuring the street dust concentration before and after sweeping. The device investigated was mounted with a gutter-broom and pick-up head. The gutter-broom worked on the innermost 38 cm of the street close to the curbs and the main pick-up hood covered the next 182 cm.

The gutter area of the streets under consideration had a higher dirt loading than the remaining streets due to water run-off. The main pick-up head used an air-jet mechanism for cleaning the street, while the gutter-broom uses a rotating-wire sweeping device.

As seen in Figure 1 the main pick-up head of the sweeper had a higher sweeping efficiency because of the air jets that blast at the road surface and lift the street dust. The gutter-broom was ineffective in removing particles smaller than 2 μm, whereas the pick-up head was equally efficient over a very wide range of particles.

As seen in Fig. 2 the overall efficiency for the main pick-up head was about 90% and about 40% for particles smaller than 15 μm.

The general conclusion is that sweeping and vacuum sweeping on artificial surfaces would have only a marginal effect on small particles unless an improved vacuum sweeper as described

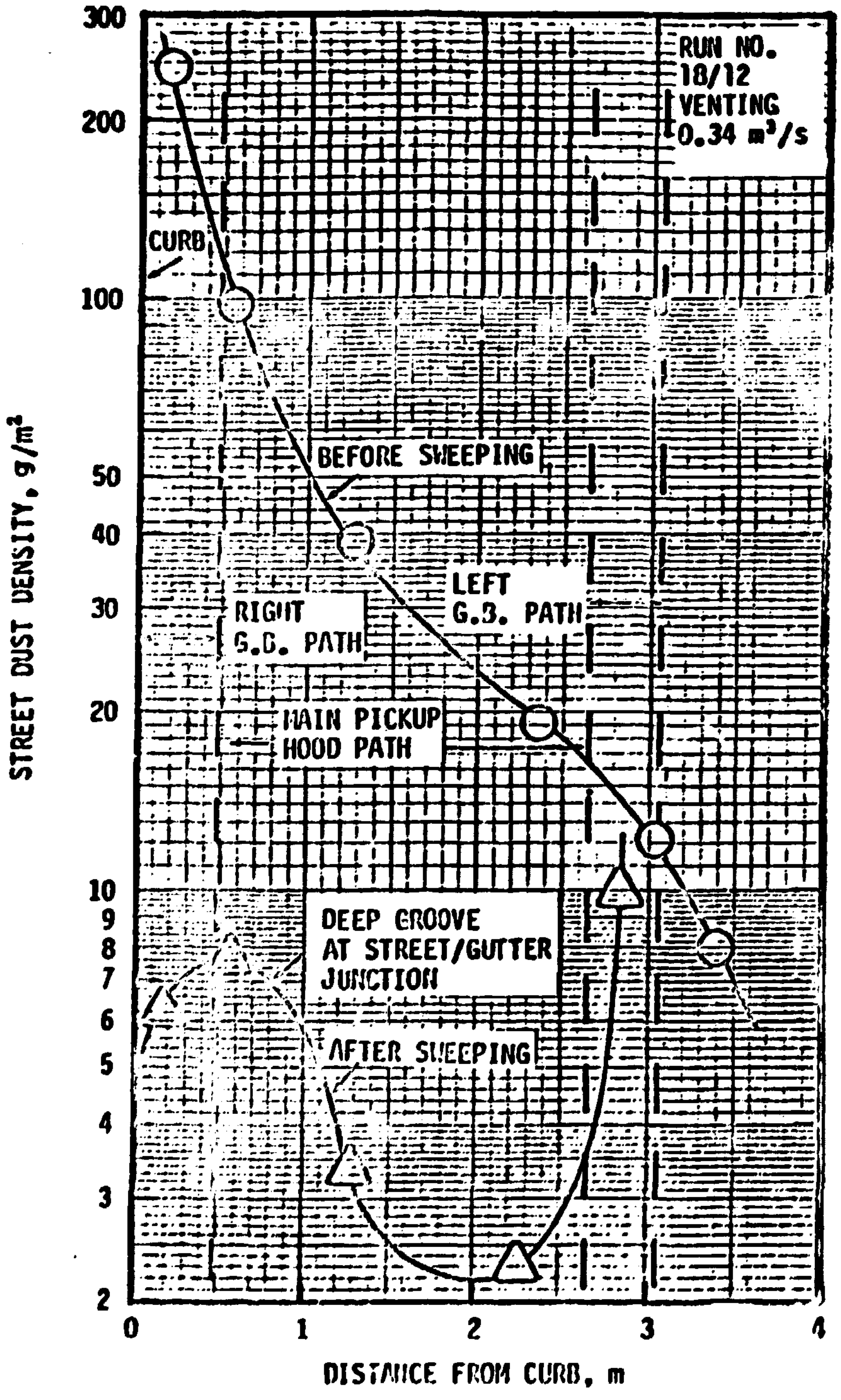

Fig. 1. Street dust distribution before and after sweeping (from Calvert 1980).

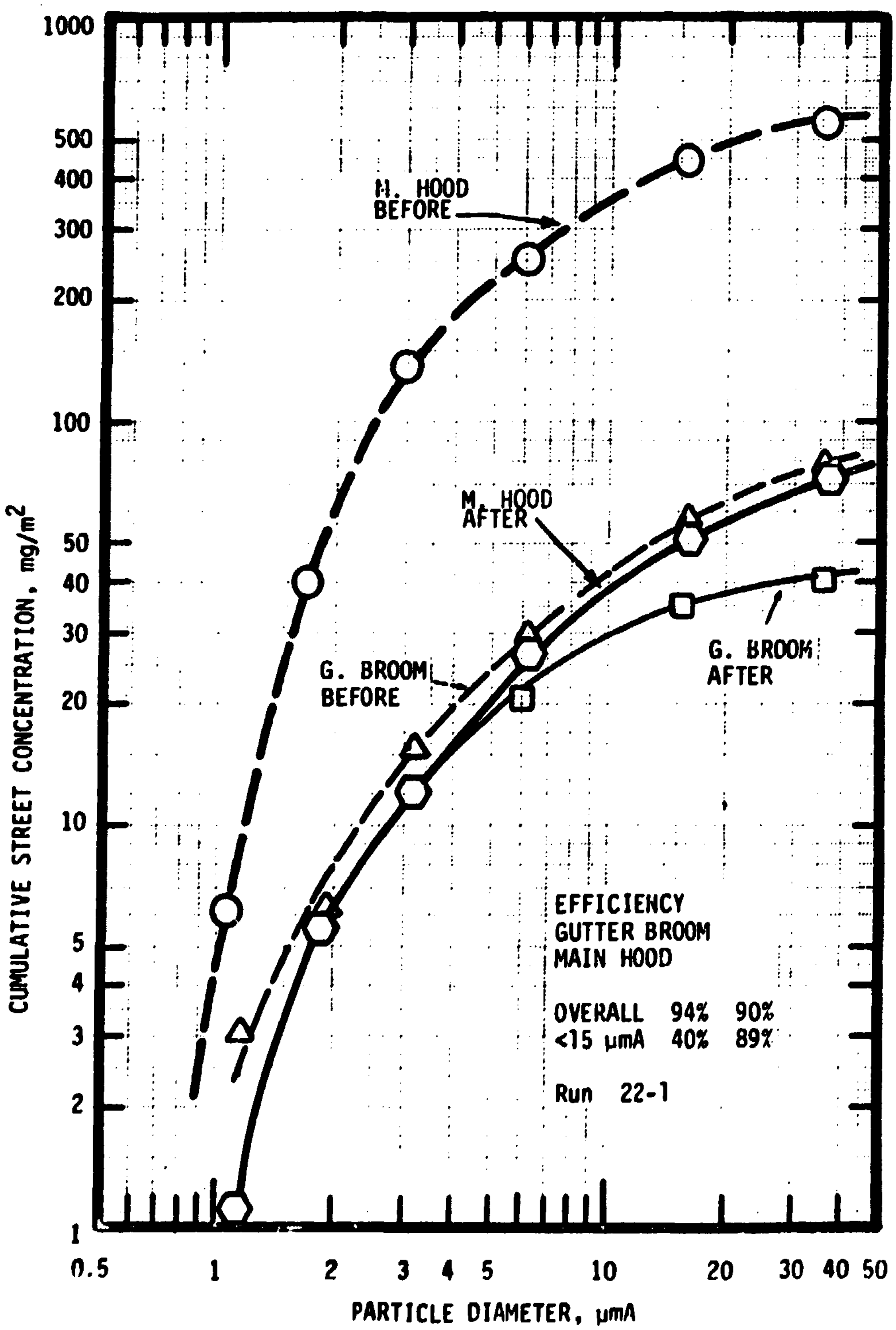

Fig. 2. Street sweeping efficiency (from Calvert 1980).

in Calvert et al. (1984) were used. In that case a decontamination factor of 2-10 can be attained. The cost of modifying a regenerative air vacuum sweeper to do this will be only about 5% of the sweeper cost. Wire brushing can be accomplished in a non-toxic environment for about \$ 0.004/m^2. (Barbie 1980).

2.1.2. Pervious surface

A small vacuum street sweeper was used for removing contamination from a clipped meadow (Menzel 1962). About half of the comtamination could be removed by sweeping the meadow twice.

A rotating-broom sweeper with steel bristles removed about 70 percent of the contamination from moist soil with a thin cover of fescue. A second sweeping gave almost 90 percent contamination removal.

2.2. Firehosing and flushing

The use of firehosing and flushing to clean hard surfaces is fast and utilises readily available equipment; in general, however, its effectiveness goes down with decreasing particle size.

2.2.1. Paved surfaces

Wiltshire et al. (1965 and 1966) performed experiments with a standard firehosing nozzle. For one pass they found decontamination factors of 10 for smoothly textured and 2 for roughly textured surfaces for loadings of 43 and 270 g/m^2 when contaminated with 44-μm particles. Because of the particle size used in this study the DF values obtained should be viewed as upper limits when considering decontamination of surfaces contaminated with small particles. Dick and Baker (1961) made decontamination experiments where the contamination consisted of plutonium particles with an average diameter of 0.8 μm. The surfaces were, amongst others, asphalt and concrete pads measuring 3.5 by 3.5 m. Decontamination factors of 10-12 for asphalt and of 4-40 for concrete surfaces were obtained after hosing with water at a pressure of 400-700 psi 2 days after contamination.

Warming (1982 and 1984a) sprayed Rb-86, Ru-103, and Ba-La-140 dissolved in water onto a dry asphalt and concrete surface. A single firehosing two days later gave decontamination factors of about 2. Decontamination after 40-50 days gave nearly no effect. The mass loading was not measured.

Clark and Cobbin (1964) performed decontamination experiments using mechanized street flushers. The contaminant were 44-100 μm particles. They found decontamination factors of 10 for mass loadings of 54 g/m^2 and of 50 for a mass loading of 130 g/m^2 for roughly textured and of about 50 for smoothly textured asphalt for mass loadings of 54 g/m^2 and 130 g/m^2.

This decontamination factor value must be viewed as an upper limit because of the large size of the contaminated particles.

Run-off studies can give some valuable information about the efficiency of firehosing and flushing streets. From such experiments, Sartor et al. (1974) found an equation for the rate at which rainfall washes loose particulate matter from street surfaces. This rate is dependent on rainfall intensity, street surface characteristics and particle size.

The equation given is

$$N_c = N_o(i-e^{-krt})$$

where N_o = initial weight of material of a given particle size, t = time of rainfall, r = rainfall intensity, N_c = weight of material of a given particle size removed after time t, and k is a constant. The constant k depends on street characteristics, but was found to be almost independent of particle size (at least within the size range 10-1000 μ).

2.2.2. Roofs

By firehosing, Owen (1960) found decontamination factors of more than 10 on flat tar and gravel roofs, and Miller (1960) obtained a decontamination factor of 3 on a concrete roof and a single roof decontaminated 2 days following the deposition.

However, the contamination in the two experiments consisted of large particles so the decontamination factor obtained must be judged as an upper limit when considering contamination of small particles.

Gjørup et al. (1985) decontaminated aged ^{137}Cs bomb fall-out contamination on roof material by flushing and scrubbing with water. The decontamination had no effect on red tile. On corrugated eternite the decontamination factor was around 2.

2.3. Vacuuming

Dick and Baker's (1966) decontamination experiments on hard surfaces involved vacuuming as well. Industrial vacuum cleaners were used for decontaminating surfaces imbedded with plutonium particles of average diameter 0.8 μm, 99% of them below 2.5 μm.

The decontamination procedure was carried out two days following deposition; Dick and Baker found an average decontamination factor of 3.

Similar results can be obtained using houshold machines, as these are as effective today as the industrial ones used by the two experimenters.

2.4. Removal of surface

In comparison to sweeping and firehosing, removal of the surface is a more expensive procedure. Some of these procedures, such as the scraping of land areas and road planing of asphalt and concrete surfaces, use readily available equipment and can be applied to a rather large area, whereas others such as sand-blasting are slow and costly and could be used only on very limited areas (see 3.1).

2.4.1. Road planer (paved surfaces)

A road planer is a commonly used tool today to remove the uppermost surface of asphalt or concrete in the renovation process of roads.

The cost of the cutting operation depends on the depth of cut and type of machine. For a given depth, one usually gains by moving to a larger machine. A cold planer of 190 cm in diameter grinding off an asphalt surface 3 cm thick can cover about 700 m surface per hour at a cost of $3/m^2 including the cost of removing the rubble. Barbie et al. (1980) found that by grinding off 1.2 cm, contamination of concrete surfaces can be carried out for about $0.3/m^2 with a speed of about 2000 m^2/h. To this figure the cost of removing the rubble must be added.

2.4.2. Earth-moving equipment (soil surface)

The deposition velocities on rough surfaces like grass, tree-covered areas, and bushes are much higher than those on the more smooth harder surfaces, and could cause more serious contamination. Costly procedures such as removing the uppermost surface and cutting the trees could, therefore, be justified.

Many common types of earth-moving equipment have been used in decontamination tests. These include graders, bulldozers, and pan-type scrapers. (Menzel 1961 a, 1961 b, and 1962 and Owen 1965). From 80 to 90 percent of the radioactive surface contaminant were usually removed when 5 cm of the soil was removed.

2.5. Other reclamation procedures

Besides decontamination, a number of dose-reduction measures could be applied to a contaminated area: plowing, digging garden, and turning flagstone. These procedures do not remove the contamination but relocate it in such a way that the dose is reduced.

2.5.1. Digging garden and turning flagstone

Gjørup et al. (1982) showed that when the radioactive material was buried effectively at a depth of one spit, and the flagstone was turned over, the dose rate from the activity deposited would be reduced by a factor of 6. This could be done by an effort of 1 person-day per 50 m^2 surface.

2.5.2. Plowing

In parks and other large areas in an urban region, plowing could be an effective tool in reducing dose. A reduction factor of 15-18 can be achieved by normal plowing. Deep plowing in which the uppermost layer of the soil is turned into the bottom of the plough furrow, can reduce the dose rate from the activity deposited by a factor of more than 50 (Hedemann 1979, Roed 1982). In the case in which a normal plowing is repeated the dose can be raised again. However, if the initial plowing burries the surface material so deep that it cannot be reached by a normal plowing procedure this effect will be absent.

2.6. Decontamination in cold weather

Routine maloney et al. (1962) tested methods for decontaminating various surfaces under cold weather condition.

Mechanical snow removal was quite effective in eliminating radioactivity from areas where a fallout simulant had been spread on top of loose snow. Under favorable weather conditions less than 5 per cent was left using either a snow plow or motor grader. More effort was required to reach the same level of decontamination with warm sticky loose snow than with cold snow. Ice and frozen ground surface was effectively decontaminated by sweeping. Hand sweeping left less than 5% of the radioactivity on ice. Mechanical sweeping left 15% on frozen ground.

Qvenild and Tveten (1984) have reported decontamination factors exceeding 100 by a procedure where loose snow was removed from the contaminated areas using a tractor with a shovel. The weather condition during the decontamination procedure was favorable.

Warming (1982) sprayed contamination on top of a snow- and ice-covered road. Decontamination factors of 3 were obtained in two weeks by ordinary snow-clearing procedures.

3. SOPHISTICATED METHODS

A number of more sophisticated techniques for removing surface contamination have been described in the literature. Halter et al. (1980) have described and compared the most important with reference to concrete surfaces. Table 1 shows this comparison.

3.1. Sand-blasting

Sand-blasting is effective only if the contamination is right on the surface. Roed (1981) has shown that only a limited part of aged ^{137}Cs contamination on roofs could be removed by this technique.

Table 1. Comparison of Various Concrete Surface Removal Techniques (from Halter and Sullivan 1980).

Technique	Limitation	Estimated Relative Speed at which a Unit of Surface Area can be removed
Sand Blasting	Grit Adds to the Contamination	Slow
Dry Ice Blasting	Very Slow Penetration	Slow
Flame Spalling	Heat May Cause Undesirable Chemical Reactions	Slow
Explosives	Generates Moderate Quantities of Dust which must be controlled	Fast
Jack Hammer	Awkward to Use on Walls	Medium fast
Impactor Powered by Air or Hydraulics	Limited to large Accessible Facilities	Fast
Scrubber or Scabbler	Awkward to use on Walls	Slow
Water Cannon		
Hand-held Modified 458 Magnum Rifle	Gun Powder Combustion Products are Produced	Slow (5-6 min/ft^2)
Rapid-Fire Model	Limited to large Accessible Facilities	Slow (3-4 min/ft^2)
Concrete Spaller with 38-Pound Air Drill to make Holes		
Hand-held		Medium fast (50-60 sec/ft^2)
Semi-automated on Platform		Medium fast (35-40 sec/ft^2)
High-Pressure Water (40,000 to 60,000 psi)	Produces contaminated Water	Fast (10-15 sec/ft^2)

Wet sandblasting of houses is today a fairly normal renovation procedure; it is slow and costly, however. The cost is about \$7 per m^2, accomplished at a speed of 10 m^2/h; but apart from this, expensive scaffolding must be erected around the house, and that slows the work.

A blasting technique using dry ice pellets has been evaluated to be even slower than sand blasting.

Sand-blasting can therefore be provided under only special circumstances, although the decontamination factor for newly deposited contaminants is high.

3.2. Flame spalling

Flame spalling can remove a 1-1.5 mm thick layer of an 1 m^2 section of concrete in four minutes (Eberling 1984). Four spallings were necessary in order to remove some aged contamination of ^{137}Cs on a concrete wall in which 4-5 mm of the surface was removed. The total cost of this procedure was estimated as 376 DM/m^2 (\$150/m^2). When the contamination is only on the surface only one spalling will be necessary and the cost will then be reduced to less than 150 DM/m^2 (\$60/m^2).

3.3. Controlled explosion

Controlled blasting has been used to remove surfaces. Although the technique is fast, the structures decontaminated need to be sturdy.

3.4. Jackhammers and impactors

Jackhammers are awkward to use on walls. An impactor, a large jackhammer-like device which must be mounted on a backhoe, can be used here. Operators can easily remove complete walls with them, yet find it difficult to remove only a 1- to 2-cm surface layer. The cost is about \$44 per m^3 of concrete removed (Thomas 1980).

3.5. Scrubber

A scrubber or scrapper works well on floors, but not on walls. Compared to other techniques it is slow.

3.6. Water cannon

The water cannon uses compressed gas to force a stream of water through a nozzle at a velocity sufficiently high to spall the surface on contact. The operation costs about \$270 per m^2 (Halter 1980). The technique is relatively slow requiring about 1 hour to remove 1 m^2 (Halter 1980).

3.7. Concrete spaller

The concrete spaller is a device that is inserted in predrilled holes approximately 5-cm deep, and an activation of a hydraulic device will then cause an average of 20-cm diameter spall. The concrete spaller has been shown to be relatively fast, removing 5-15 m^2 per hour (Halter 1980).

4. CONCLUSION AND DISCUSSION

As a result of a reclamation procedure, the dose reduction effect depends on a number of factors, e.g. the structure and loading of the surface, the time elapsed from the contamination until the decontamination procedure is carried out, and whether it has rained before, during, or after the contamination.

The effect of the reclamation procedure also depends strongly on the order in which the different decontamination and other dose-reducing procedures are used, e.g. to be effective, vacuum procedures have to be carried out before water is used. In the same way scraping is useless if the land has been plowed after being contaminated, prior to the scraping.

Furthermore, it is important to know the deposition velocities and the run-off effect on the different surfaces involved in order to form a carefully conceived plan where the resources are used in the most reasonable way. It must be realised that some of the more sophisticated decontamination procedures are sufficiently costly to make property condemnation a serious alternative.

It can be concluded that a data bank containing the parameters described above as well as the necessary information about the various surfaces in the sites under consideration will help greatly in planning a reclamation operation. To some extent, this has already been carried out in the USA. (Tawil 1984).

Although it is impossible to give decontamination factors for different types of surfaces in detail without knowing the various parameters that determine them, some general observations will be given below:

Decontamination of roof and wall surfaces are difficult. However, decontamination shortly after the deposition takes place could reduce the radiation level by a factor of two using vacuum sweeping and firehosing.

Paved areas are also difficult to decontaminate. Depending on the state of the surface, decontamination factors from 2-10 are realistic using vacuum sweeping and firehosing. Unpaved areas, such as park lawns gardens etc., are much easier to decontaminate; decontamination factors here of 100 or more are realistic using a scraping procedure. Paved areas covered with snow are easily decontaminated, and here decontamination factors of more than 100 can be obtained.

Fortunately, the surfaces easiest to decontaminate are also those that are most likely to be heavily contaminated in a specific area, for example, a lawn.

Only simple and relatively cheap procedures such as sweeping, vacuum sweeping, firehosing, digging in gardens, plowing, scraping, etc. can normally be justified in a reclamation procedure. Also road planing can be feasible, as the cost of this procedure has been reduced considerably during the last few years.

5. RECOMMENDATION FOR FUTURE WORK

The decontamination effect of vacuum sweeping, sweeping and firehosing for paved areas and small particles ($< 4\ \mu m$) as well as the run-off effect are not nearly sufficiently known. A major effort to conduct a series of experiments should be made in order to clarify the efficiency of these means in the reclamation procedure.

Also, it is recommended to make a European data bank containing all the parameters necessary to plan the reclamation procedure in the event of a contamination taking place. This presumes knowledge of the distribution of the different types of surfaces in the areas under consideration.

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Abstract

A literature study was conducted in order to compare the effectiveness and cost of different reclamation procedures that may be employed after an accident on a nuclear facility takes place in which radioactive material is released to the atmosphere.

A substantial amount of work has been done on reclaming soil and snow-covered surfaces. Using scrapers or other soil-moving equipment decontamination factors are 10-100. (The decontamination factor is the ratio of the contamination before to that after the decontamination procedure). However, information on decontamination of paved areas by simple methods such as firehosing and vacuum sweeping are poorly documented. Therefore, only a very uncertain figure in the range 2-10 can be given for the decontamination factor here. It is recommended that a major effort be made in the future to investigate the efficiency of these simple methods, because of their relatively low cost. Also, more expensive methods for reducing the dose such as vacuuming, road planing and deep plowing are treated because of their feasibility under cer-

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tain circumstances. Using these methods dose reduction factors in the 2-100 range can be obtained. Very expensive techniques, such as sandblasting, water cannon, flame spalling, etc. are justifiable usable only in special situations and are therefore considered very briefly here.

The methods vary widely in cost. A simple method like vacuum sweeping costs $0.004 per square meter of surface; whereas one like road planing can reach $4 per square meter. A more sophisticated technique like flame spalling costs as much as $100 per square meter.